



U.S. DEPARTMENT OF
ENERGY

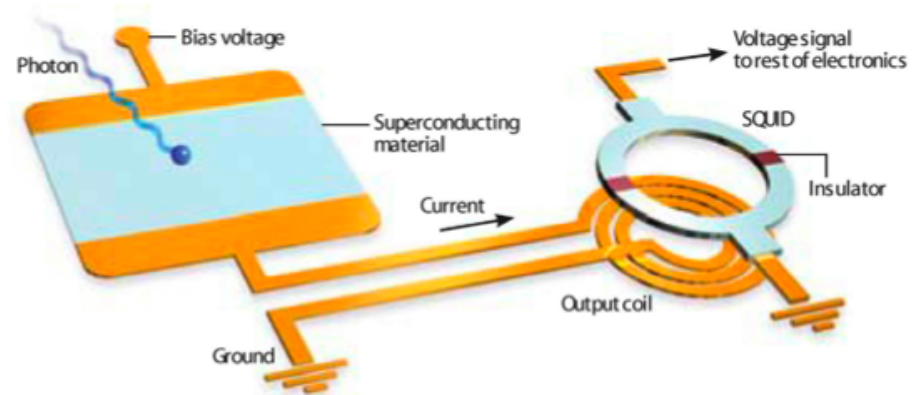
Nuclear Energy

Nuclear Energy University Programs (NEUP) Fiscal Year (FY) 2013 Annual Planning Webinar

Nuclear Materials Control and Instrumentation

Daniel A Vega
Federal Program Manager

August 2012





Mission and Program Objectives

Mission

Ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions.

Goal 3: Secure Our Nation

- Enhance nuclear security through defense, nonproliferation, and environmental efforts.

DOE



Advance nuclear power as a resource capable of making major contributions in meeting the Nation's energy supply, environmental, and energy security needs by resolving technical, cost, safety, security and regulatory issues through research, development, and demonstration.

NE



Develop Used Fuel waste management strategies and sustainable fuel cycles that improve resource utilization, minimize waste generation, improve safety and limit proliferation risk.

FCRD

Program Objectives

**Near
Term**

- Address BRC recommendations for Used Fuel Disposition.
- Increase focus on accident tolerant fuels.
- Down select fuel cycle options for further development.

**Medium
Term**

- Conduct science based, engineering driven research for selected fuel cycle options.
- Complete implementation plan for developing a Test and Validation Complex for extended storage of used nuclear fuel.
- Evaluate benefits of various geologic media for disposal.

**Long
Term**

- Demonstrate the selected fuel cycle options at engineering scale.
- Execute Test and Validation Complex for extended storage of Used Fuel.
- Conduct engineering analysis of disposal site(s) for selected geologic media.



Where Are We Today? Working Toward an Integrated Approach

Front End

Back End



Uranium Resources

- Conventional production
- Innovative approaches
 - U Seawater



Fuel Fabrication

- Safety enhanced LWR fuel
 - Accident tolerance
- Higher performance
 - Improved burnup

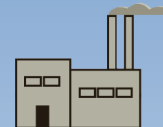


Reactors



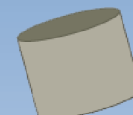
Interim Storage

- Evaluating extended time frames
- Transport after storage



Recycle

- Separations
 - Recycled fuel
- Secondary waste treatment



Disposal

- Alternative geologies
- Alternative waste forms

Optimize through systems analysis and engineering.



Nuclear Energy R&D Roadmap (2010)



NUCLEAR ENERGY RESEARCH AND DEVELOPMENT ROADMAP

REPORT TO CONGRESS

April 2010



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- “Roadmap for the Department of Energy’s RD&D activities that will ensure nuclear energy remains a viable energy option for the United States.”
- Delivered to Congress in April 2010
- Defined four main R&D objectives
- **R&D Objective 4:**
“Understand and minimize the risks of nuclear proliferation and terrorism”

MPACT Addresses R&D Objective 4



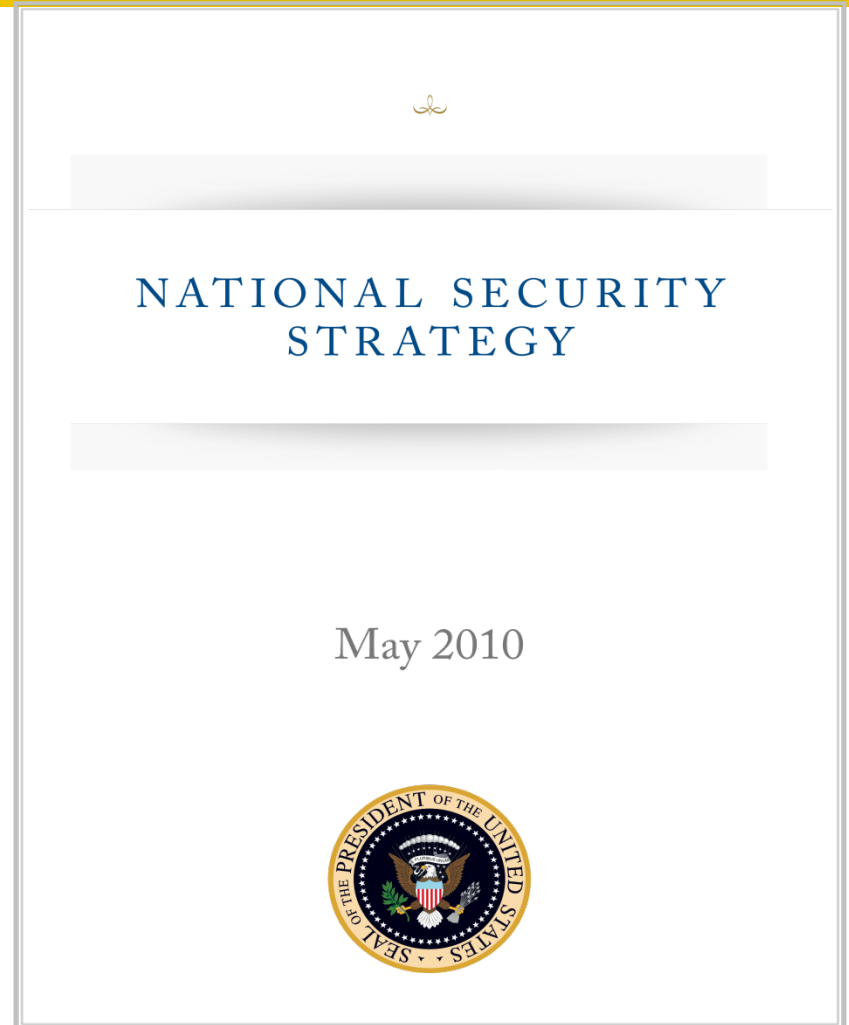
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Importance of Nuclear Proliferation and Terrorism

- “There is no greater threat to the American people than weapons of mass destruction, particularly the danger posed by *the pursuit of nuclear weapons by violent extremists and their proliferation to additional states.*”

MPACT and indeed the broader
NE program are part of
the national response





Materials Protection, Accounting, and Controls Technology (MPACT) Mission

- 1) Develop innovative technologies and analysis tools to enable next-generation nuclear materials management for future U.S. nuclear energy systems**
 - Technologies:
 - Protection, accounting and control are the key elements of nuclear materials management
 - Accounting and control have been emphasized in MPACT
 - Analysis tools:
 - MPACT-specific analysis tools for planning (design), implementation, evaluation
- 2) Supports the other FCT Campaigns with enabling technologies and analysis tools and provides key linkages to**
 - Used Fuel Security
 - Process monitoring and controls
 - Support Fuel Cycle Options (FCO) study



Program Organization Structure

- **One of the three Fuel Cycle R&D Campaigns, managed by**
 - Federal Program Manager (Daniel Vega, DOE Headquarters)
 - National Technical Director (Mike Miller, LANL)

- **\$5-\$7 Million Budget to support**
 - Nuclear Materials Control and Instrumentation
 - Analysis Tools
 - Safeguards and Security by Design
 - Used Fuel Security
 - Proliferation and Terrorism Risk Assessment



Near and Medium-term Needs

Key Issue	Drivers
Security of <u>extended fuel storage</u>	<ul style="list-style-type: none">• Blue Ribbon Commission recommendations• Industry interest• Post-Fukushima questions about security as well as safety (see, for example, BRC report)
NRC Rulemaking on <u>Reprocessing</u>	<ul style="list-style-type: none">• Exclusion of reprocessing facilities from Category I MC&A requirements (10 CFR 74.51)• Risk informing NRC's Safeguards and Security Requirements• Diversion Path Analysis (DPA)
Material protection, accounting and control for <u>electrochemical processing</u>	<ul style="list-style-type: none">• High-priority U.S. government policy initiative• US/ROK Joint Fuel Cycle Study• Domestic shift of emphasis to non-aqueous• Note also: IAEA studies of electrochemical safeguards (but this falls under NNSA purview)
Fuel Cycle <u>Options Study</u>	<ul style="list-style-type: none">• enabling technologies and analysis tools to provide prudent safeguards and nonproliferation analysis



Long-term Challenges

Nuclear Energy

Key Issue	Drivers
<u>U.S leadership</u> on issues of nonproliferation, security, counterterrorism, in connection with U.S. nuclear energy	<ul style="list-style-type: none">•Blue Ribbon Commission recommendations (“urgent need” identified by Blue Ribbon Commission)•March 2012 Nuclear Security Summit•White House, NSC staff•Long-term R&D needs (see BRC) with both domestic and international implications•<i><u>Innovative, long-range R&D can provide key leverage for U.S. leadership</u></i>
Material protection, accounting and control for <u>advanced fuel cycles</u>	<ul style="list-style-type: none">•Advanced fuel cycle facilities may be large and complex. MC&A may be expensive and complex•Advanced fuel fabrication, depending on what sort of advanced fuels are developed, or enrichment (if called upon)•Threats, both insider and outsider, may continue to become increasingly sophisticated and capable



Nuclear Materials Control and Instrumentation (FC-3)

“ ...develops technologies and analysis tools to support next generation nuclear materials management and safeguards for future U.S. fuel cycles. This includes both extrinsic measures and safeguards over-laid on a nuclear energy system, as well as the intrinsic design features incorporated into system design. New technologies and approaches to in-facility accounting and control/safeguarding of nuclear materials will be pursued under this research area. This research topic will also pursue nano-technology and nano-materials as they relate to sensors, detectors, and nanoparticle signatures, and other advanced measurement techniques that could complement the ongoing measurement program. Key university research needs for this activity include:”



Nuclear Materials Control and Instrumentation (continued)

- a) New and improved detector systems and sensor materials that can be used to increase the accuracy, reliability, and efficiency of nuclear materials quantification and tracking from the perspective of the operator or state-level regulator. Such systems could include new neutron methods, spectroscopic analysis, chemical, calorimetric, or other non-nuclear methods, as well as any other novel methods with potential MC&A benefits.**
- b) Methods for data integration and analysis, include cutting-edge work in multi-variant statistical techniques for process monitoring, risk assessment, plant-wide modeling & simulation directed at the accounting challenges of high-interest fuel cycle processes, including advanced separations processes;**



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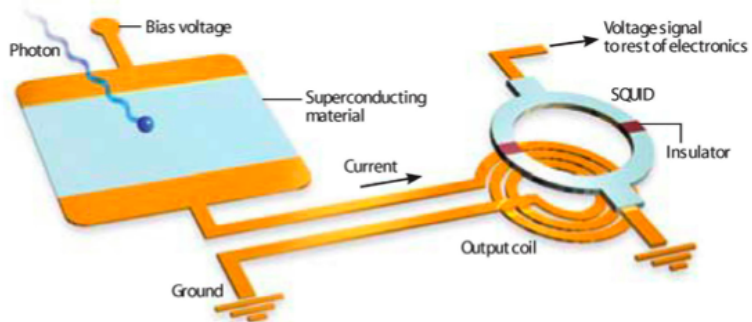
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Nuclear Materials Control and Instrumentation – Ongoing Projects

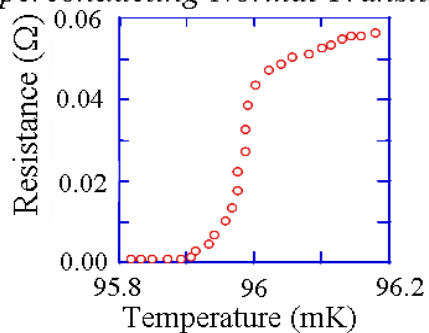


Microcalorimeter Detector

Superconducting transition edge sensor measures temperature change from individual photons

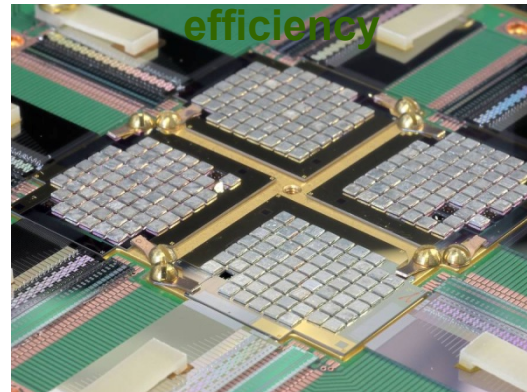


Thermometer:
Superconducting-Normal Transition

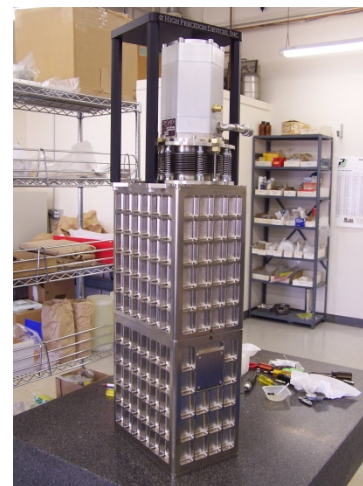


Pixel arrays increase detection

efficiency



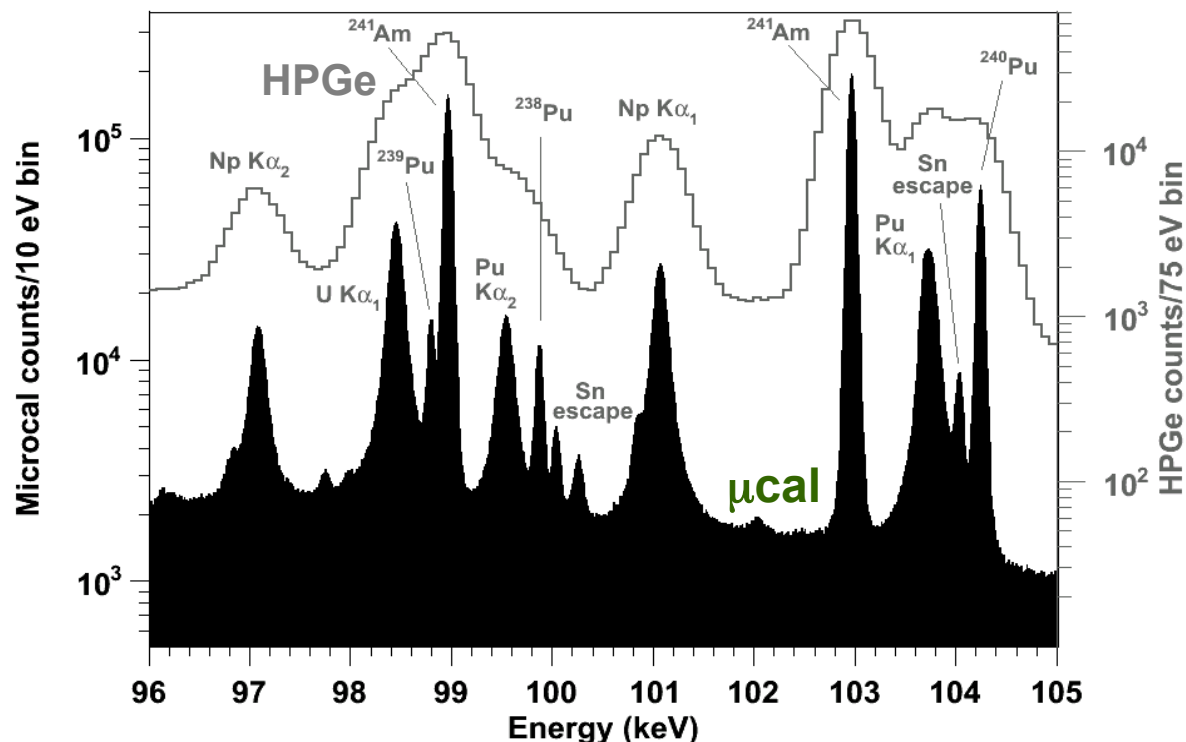
**Sample is outside of
dry cryostat (no
liquid cryogens)**





Spectroscopic Capability

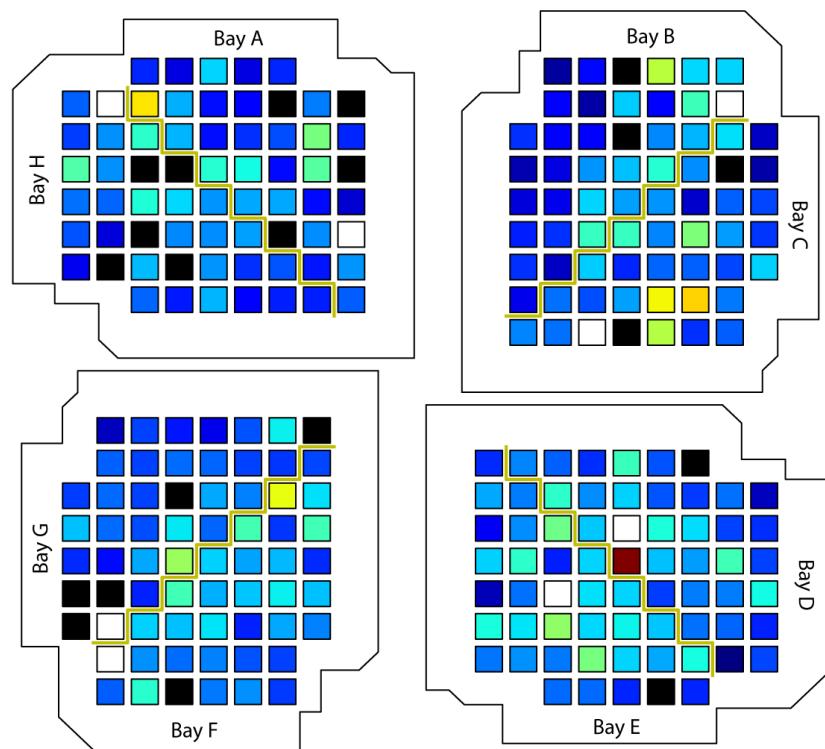
- Significantly improved capability for gamma-ray spectroscopy
 - Factor of 5 to 10 better energy resolution than HPGe for measurement of plutonium samples



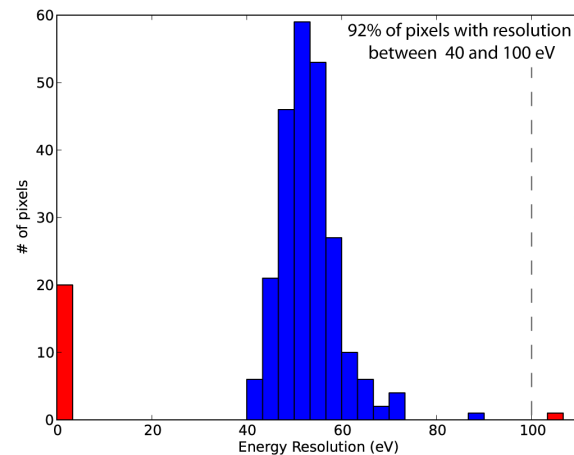
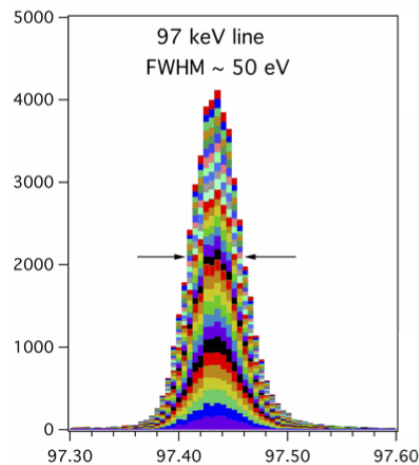
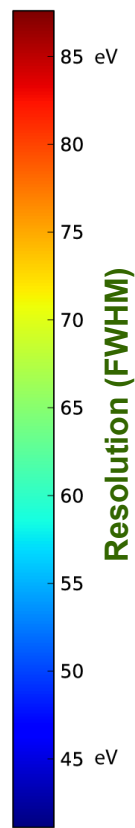


Major Recent Result: 92% Pixel Yield from 256-Pixel Array

GammaBox6 Energy Resolution Map



■ Resolution spec not met □ Not connected to readout





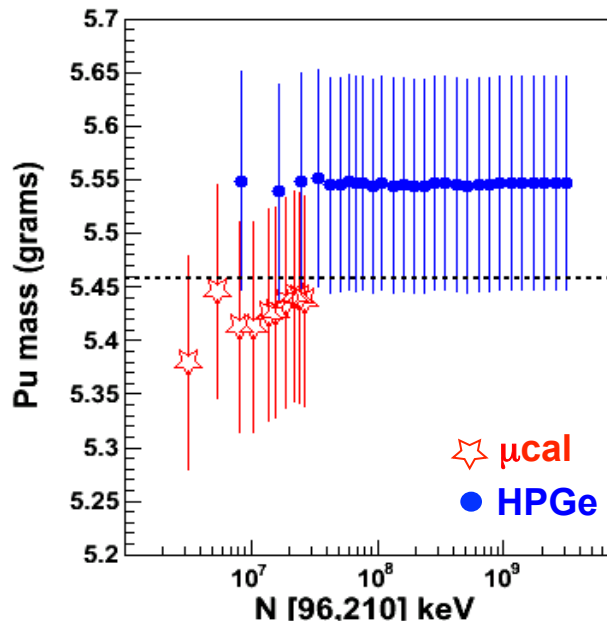
Major Recent Result: Pu Mass from Combination of Microcalorimeter and Macrocalorimeter

■ Pu mass measurement

$$m_{\text{Pu}} = \frac{W}{P_{\text{eff}}} = \frac{W}{\sum P_i R_i}$$

← Total power from “macro-”calorimeter

← Effective power from microcalorimeter gamma-ray isotopics

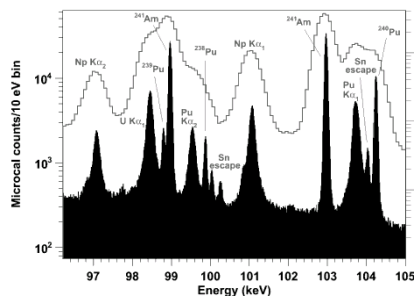


- First demonstrated capability of microcalorimeter to measure complete Pu isotopics and Pu mass
- Uncertainty of this measurement dominated by “macro-”calorimeter total power (~1.8%); Larger sample or small-sample calorimeter could provide smaller uncertainty on total power

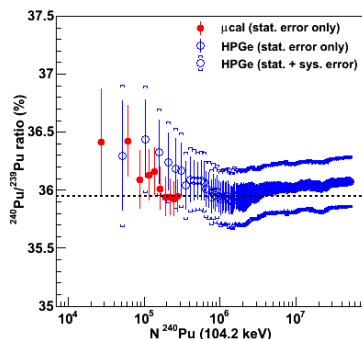


Microcalorimetry for Ultra-High Resolution x- and gamma-ray Spectrometry

5-10 times better resolution than HPGe...



More accurate, more precise isotopic determination...



POCs: Andrew Hoover, Michael Rabin (LANL), with NIST and other collaborators

Statement of the MPACT Need: Significantly improved gamma spectrometry to provide highly accurate and precise material accountancy and quality assurance during fuel cycle processes via NDA technique.

Key Outcomes: Develop new NDA technology approaching DA-like accuracy/precision

Technical Challenges

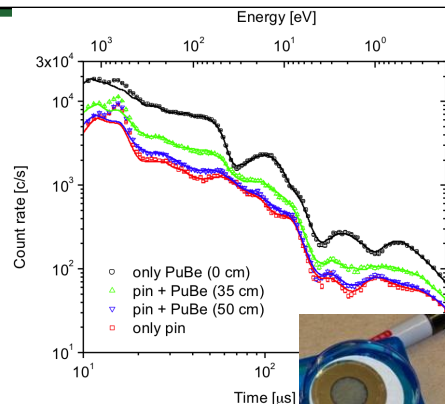
- Fully proven array-based instrument validated by measurements on nuclear materials
- High count rates and high resolution
- High pixel yield
- Advanced quantitative analysis tools for completely new technology

FY2011 Accomplishments

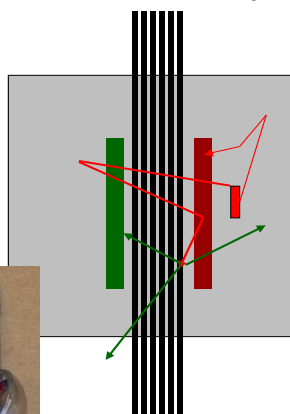
- Demonstrated capability of microcalorimeter technology to perform plutonium isotopics and plutonium mass content determination with better performance than HPGe using a 256-pixel microcalorimeter array for ultra-high resolution gamma spectrometry.



Lead Slowing-Down Spectrometry for Direct Measurement of Actinides in Used Fuel



Fuel assembly



POCs: Glen Warren (PNNL), Victor Gavron (LANL), Yaron Danon (RPI), Denis Beller (UNLV), George Imel (ISU)

Statement of the MPACT Need: Direct, accurate measurement of fissile isotopes (e.g. Pu-239 and U-235) in used fuel and bulk materials.

Key Outcomes: Modeling studies of LSDS efficacy for assay of bulk materials, experimental validation, development of fast-neutron detector.

Technical Challenges

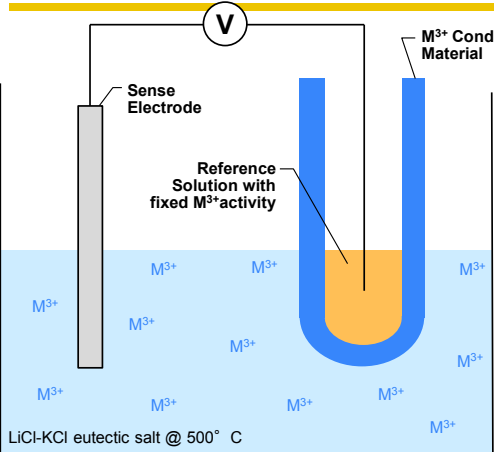
- ◆ Study, develop and evaluate candidate time-spectra analysis methods;
- ◆ Develop enabling fast-neutron detection instrumentation specific to requirements of LSDS;
- ◆ Perform testing of neutron instrumentation at LANSCE and RPI;
- ◆ Perform benchmarking of simulated assay and diagnostic signals at LANSCE and RPI.

2011 Accomplishments

- Developed and tested empirical algorithm for self-shielding to compare with analytical model, with promising preliminary results.
- Benchmarking measurements at RPI and LANSCE revealed some differences between measured and predicted results. Several phenomena have been identified to account for others, e.g., trace levels of hydrogen in lead.
- Improved deposition of ultra-depleted uranium for threshold fission chamber.
- Identified new neutron detection approach with very large potential gains in efficiency



Actinide Sensor for Electrochemical Process Monitoring

 <p>Potentiometric Sensor that measures the potential difference between sense and reference electrodes to determine concentration</p> <p>LiCl-KCl eutectic salt @ 500° C</p>	<p><u>POCs:</u> Brenda Serrano-Rodriguez (INL), Guy Fredrickson (INL), Peter Zink (Boston University)</p> <p><u>Statement of the MPACT Need:</u></p> <ul style="list-style-type: none">◆ Real-time, in-process measurements of actinides in electrochemical processes to improve detection and assurance <p><u>Key Outcomes:</u></p> <ul style="list-style-type: none">◆ In-process, real-time actinide sensor
<p><u>Technical Challenges</u></p> <ul style="list-style-type: none">◆ Majority of published β''-alumina ion exchange research has focused on single crystals◆ The polycrystalline β''-alumina needed for this type of sensor has shown lower conductivity◆ Selectivity of β''-alumina: sensor needs to respond only to ions of interest◆ Choice of reference electrode can have a profound effect on sensor response, sensitivity and stability◆ Trivalent ion exchange into β''-alumina might cause stress sufficient to weaken the material	<p><u>FY2011 Accomplishments</u></p> <ul style="list-style-type: none">◆ Performed ion exchange tests with intermediary size and valence ions precursors to determine if it improves sensor material integrity.◆ Investigated the effect of eutectic LiCl-KCl on the Gd-exchanged ceramic.

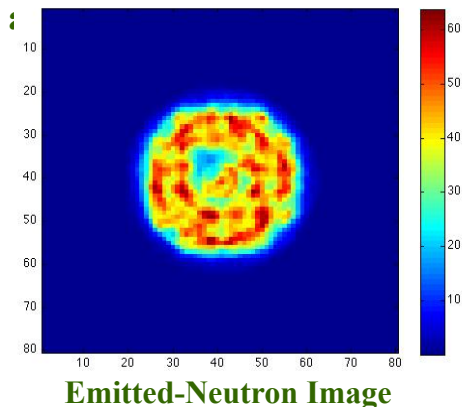


Fast-Neutron Imaging to Quantify Fuel-Cycle Materials

Proof-of-concept tomographic pin-by-pin neutron



Assembly of Fuel
Elements with Single
Defect (marked by "x")



Emitted-Neutron Image

POC:

Paul Hausladen (ORNL)

Statement of the MPACT Need: Neutron imaging to strengthen material control and accounting for difficult to measure material in inventory, e.g., holdup

Key Outcomes: Proof-of-concept tomographic emitted-neutron imaging to enable assessment of individual fuel pins in an assembly

Technical Challenges

- ◆ Emitted-neutron tomography with sufficient resolution to identify individual fuel elements is only possible with magnifying optics and a thick collimator for high contrast
- ◆ Gamma ray dose to neutron detectors needs to be controlled
- ◆ Neutron self-attenuation can be quantified with addition of known source

FY 2011 Accomplishments

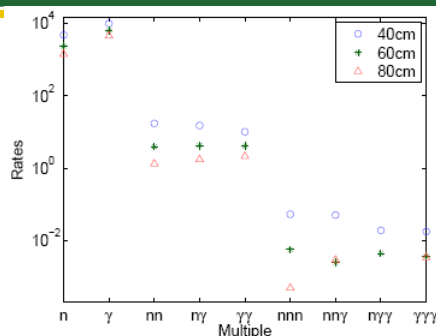
- ◆ Designed and built fast-neutron collimator
- ◆ Performed emitted-neutron tomography of multiple neutron source at ORNL
- ◆ Perform emitted-neutron tomography of assemblies of fuel-cycle materials at INL
- ◆ Detected defect of a single DU pin in an array of 32 Pu MOX pins



Fast Neutron Multiplicity Analysis



Four large liquid-scintillator detectors are shown here being used to analyze a storage can of MOX fuel pins.



Observed singles, doubles, and triples count rates from the MOX fuel shown to the left.

POCs: David Chichester (INL), Sara Pozzi (U. Michigan), Paul Hausladen (ORNL)

Statement of the MPACT Need:

Alternatives to existing helium-3 based neutron detection are needed. This project is examining the potential benefits of combining active neutron interrogation with liquid scintillator-based multiplicity analysis techniques.

Key Outcomes:

Develop and demonstrate the use of active neutron interrogation to improve multiplicity analysis measurements; also support ORNL testing of neutron imaging.

Technical Challenges

- ◆ Using digital pulse shape analysis with active interrogation for multiplicity analysis and the use of active multiplicity counting with liquid scintillators in this context.
- ◆ Developing a modeling framework with sufficient fidelity to accurately simulate higher-order interrogation coincidences.
- ◆ Satisfactorily dealing with and recovering from neutron generator bursts to collect data in-between neutron pulses.

FY2011 Accomplishments

- ◆ Developed a comprehensive, time-dependent modeling & simulation framework to evaluate time-correlated liquid scintillator response measurements for active neutron interrogation multiplicity analysis.
- ◆ Carried out benchmark measurements of tagged-neutron associated-particle active interrogation multiplicity analysis using nuclear fuel.
- ◆ Evaluated the feasibility and benefits of using time-tagged active neutron interrogation multiplicity analysis.
- ◆ Supported ORNL fast neutron imaging experiments at INL .